Studies of Positronium Decay Modes Using GAMMASPHERE

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We have begun an experiment to measure decay modes of positronium (the bound state of a positron and an electron) using Gammasphere off-line at the 88" Cyclotron.

Unlike ordinary atoms, positronium (Ps) is an eigenstate of the charge conjugation symmetry operator, C. This presents an opportunity to test C symmetry conservation in a leptonic system. The physics of Ps is governed by Quantum Electrodynamics (QED) to high precision, offering a QED test at high radiative orders -- up to α^9.

Ps atoms are formed in two states, para-Ps, $^1S_0$ or ortho-Ps, $^3S_1$. The eigenvalues of C for these states are +1 and –1. Since the photon has an intrinsic C eigenvalue of –1, para-Ps is constrained by C symmetry to decay to 2 photons (or an even number), while ortho-Ps must decay to 3 photons (or an odd number). The branching ratio for p-Ps to decay to 4 photons has been calculated in QED to be 1.48×10^{-6}, while the branching ratio for o-Ps to 5 photons is 0.959×10^{-6}. The 4 γ branching ratio has been measured with an uncertainty of 8%[1], while the 5 γ decay mode has been observed at the 1σ level [2]. The limit for a C violating decay of o-Ps to 4 γ (instead of 3) is a branching ratio of $< 2.6 \times 10^{-6}$ [4]. These measurements required dedicated apparatus and acquisition times longer than five months. Gammasphere, with its high efficiency and resolution, should allow improving these measurements with a run time of only 15 days.

We formed Ps in Gammasphere using a ^{22}Na source of low-energy positrons. The positrons are stopped in a sphere of silica aerogel. As they stop in aerogel grains, they capture electrons, forming Ps. The Ps migrates from the aerogel grain to interstitial spaces, where it decays with little perturbation from the material [3]. ^{22}Na is a good e+ source because of the low endpoint energy, long half-life, and the prompt 1275 keV gamma ray in 99% of the e+ decays. The 1275 keV γ provides a start signal for the Ps decays, allowing discrimination between long-lived o-Ps and short-lived p-Ps.

During a three-day run in September 2000, we produced a higher rate of detected Ps than any previous experiment. With a data sample of 5×10^9 events, 10^8 Ps decays were counted. Using simple data cuts, we observed 10^6 3 photon decays of O-Ps and 4x10^7 2-photon decays of P-Ps. We found 497 4-photon decays with timing consistent for P-Ps decay, but deeper analysis to reject scattered events requires simulating the kinematics of the higher-order annihilation processes. Planned improvements for a longer data run in 2001 include an external β detector to gate Gammasphere and improve Ps detection efficiency, and using the BGO detectors in veto mode to suppress scattered events, the main source of 4 and 5 γ backgrounds in Fig. 1.

References

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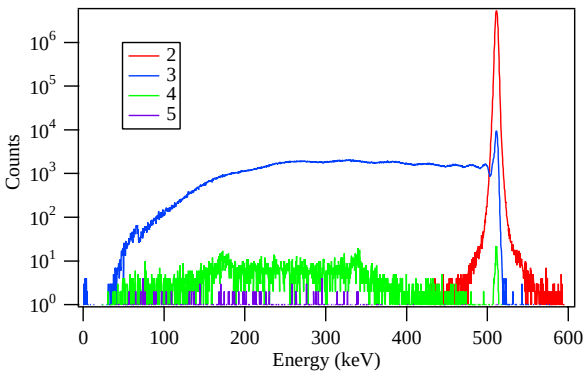

Fig. 1. Energy spectra of Ps annihilation photons in Gammasphere in a 3-day run in September, 2000. Ps events have three or more hit detectors, one photopeak 1275 keV γ, and sum energy = 1022 keV. Candidate events for 2, 3, 4, and 5 photon annihilation are shown.